

The level of capacity exhibited by Teletrac and METS suggest that their systems were designed (and, in the case of Teletrac, initially deployed) to satisfy narrowly defined market applications like stolen vehicle recovery. Unlike ARRAY™, these systems were not designed to achieve the capacity needed for applicability to a broad range of traffic and mobile resource management applications that span over many product markets, as typified by the many differing requirements embraced within the IVHS initiatives of the Intelligent Vehicle-Highway Systems Act of 1991 (e.g., advanced traffic management, enhanced traveler information, commercial vehicle operations, and advanced public transportation systems).

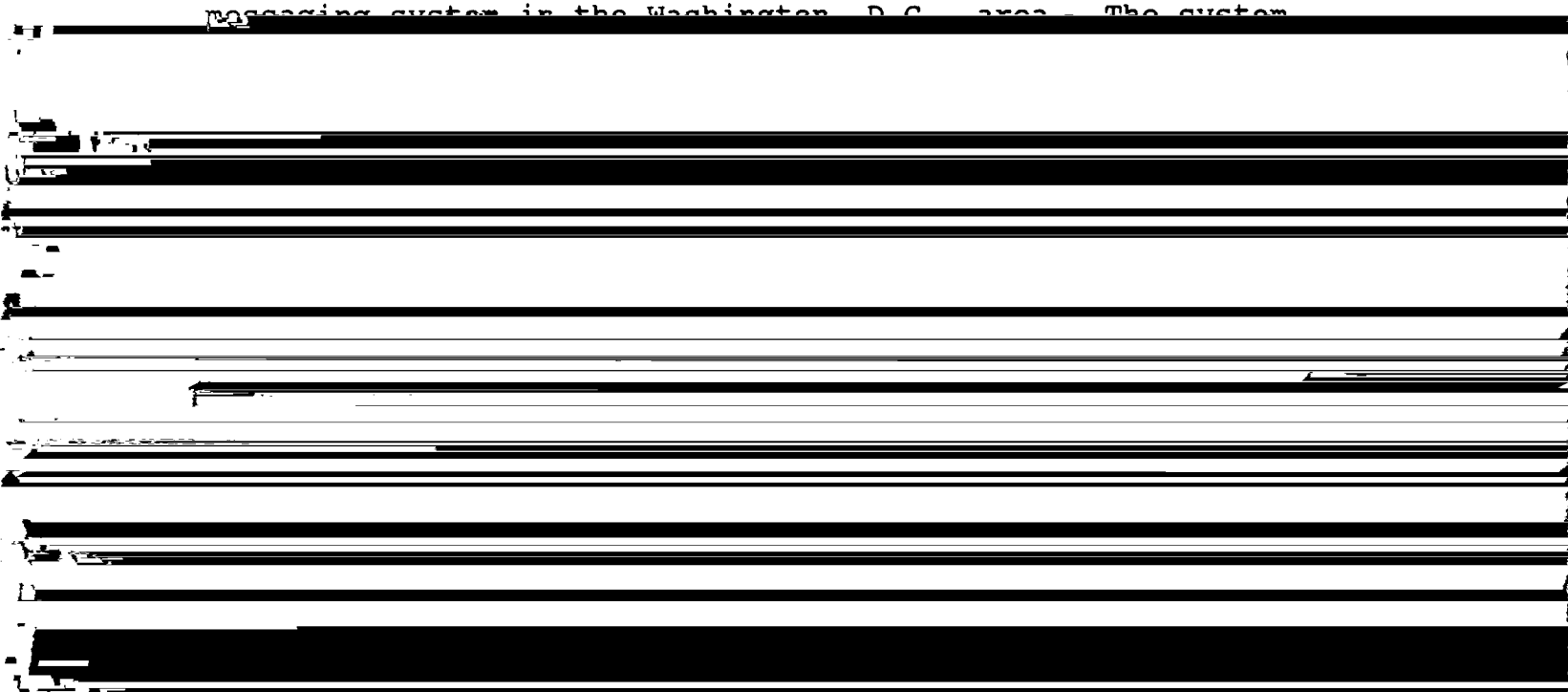
At best, the technologies of Teletrac and METS are only marginally capable of satisfying the early needs of IVHS (at 2% to 3% penetration in a moderate market), and then only if their total capacity were dedicated to IVHS functions. However, as the IVHS market matures, the benefits of IVHS are more widely appreciated, equipment and service costs continue to fall, and the market expands, the systems of Teletrac and METS, as publicly described, will be unable to keep pace with the requirements in a moderately sized city. Even before IVHS has had the opportunity to reach threshold market penetration in a million-plus market

(e.g., Orlando or Louisville), their maximum capacity will already have become saturated.<sup>7</sup>

In comparison, a well designed hyperbolic multilateration system, such as the ARRAY™ system currently being tested in Washington, D.C., avoids these capacity limits. Multifunction waveforms combine position location and data transfer functions. Wider bandwidths and higher powered mobile transceivers dramatically increase the throughput while reducing the sensitivity to interference. Dynamic clustering allows frequency reuse within a metroplex. A WELL DESIGNED HYPERBOLIC MULTILATERATION SYSTEM PROVIDES THE CAPACITY NEEDED FOR A MATURE IVHS IN A MAJOR METROPLEX.

B. Results from the ARRAY™ Experimental System Confirm Its Suitability for IVHS and the Feasibility of Wide-Area System Sharing

Pinpoint has deployed an experimental radiolocation and messaging system in the Washington, D.C. area. The system



gather data on its performance, to validate the design predictions for national system buildout, and to explore alternative software and hardware approaches to the implementation of various network functions. Photographs of the system are attached hereto.

Results from Pinpoint's experimental system to date have demonstrated that the ARRAY™ system, like the Teletrac system, operates close to the Cramér-Rao bound. However, it is critically important to note that the bound does not illustrate, in itself, the character or limits of a system. The Cramér-Rao bound only illustrates the relative tradeoffs of system design parameters, such as bandwidth, power, and position-fixing time. For example, the design objectives of the ARRAY™ system are significantly different from those chosen for the Teletrac system, but both operate close to the Cramér-Rao bound. Teletrac's approach is a low-power approach, to the detriment of the position fixing rate. In contrast, ARRAY™'s position-fixing throughput was a critical design parameter, since it directly affected the economic viability of the system to meet IVHS applications. Throughput affects both network revenue generation and the cost of service to the user.

Another central performance criterion for the ARRAY™ system was reliable operation within the predicted noise environment of the 902-928 MHz AVM band. Pinpoint recognized the need to share the band with co-primary local area systems, as well as Part 15

users and amateur operations despite their secondary status. ARRAY™'s high-position fixing rate therefore required a relatively high-power approach, given the interference noise level expected in the AVM band.

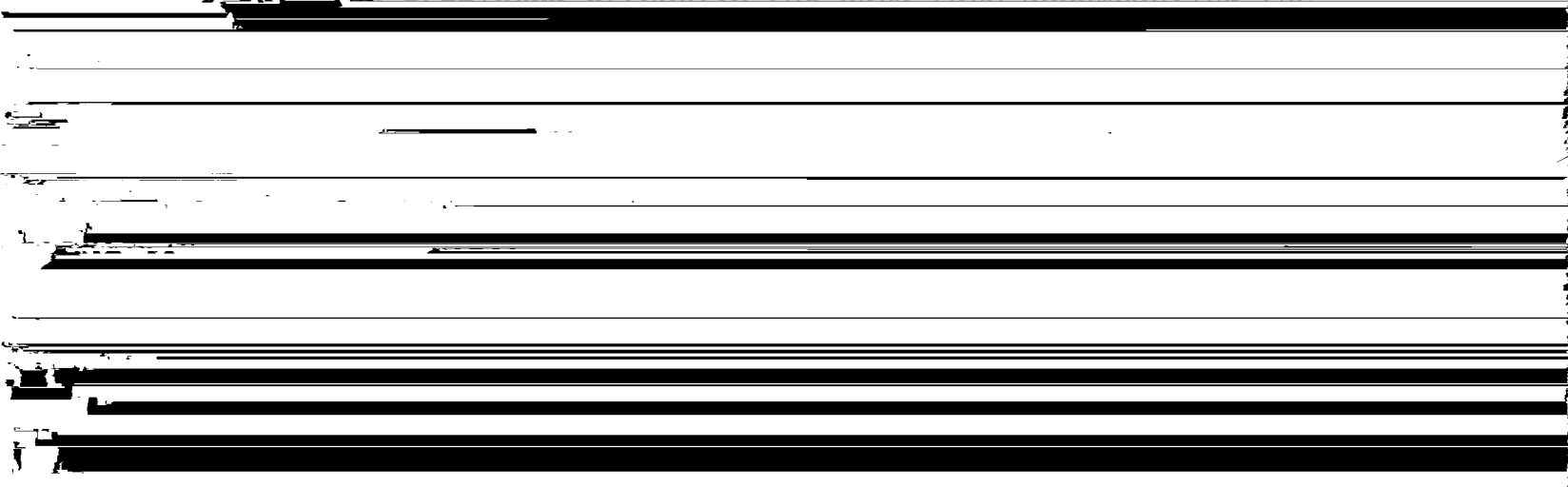
The experimental ARRAY™ system is designed as a time-difference-of-arrival, hyperbolic multilateration, radiolocation system that carries high-speed two-way data in its radar-like, spread-spectrum ranging pulses. It uses multifunction pulses to simultaneously pass data in the radiolocating protocol and to improve the radiolocation resolution of any particular time-of-arrival estimate at the base stations.

With its experimental 16 MHz bandwidth system, Pinpoint achieves a randomly-addressed mobile-unit position fixes in less than 1020 microseconds per fix. The Cramér-Rao bound within which this experimental system is working has a sigma of 2.4 nanoseconds. A protocol feature halves the time per fix when performing fixes on sets of vehicles that have been assigned to

about 1020 microseconds per packet of 24 bytes. The effective raw data rate obtained in the experimental system is thus about 185,000 bps.<sup>8</sup>

This data rate is presently limited by a target-cost constraint for the experimental system. The practical maximum throughput that can be achieved by the data signalling approach used in the ARRAY™ system is not constrained by technical issues, rather they are constrained by market target cost tradeoffs. Raw data rates near a megabyte per second can economically be achieved in a system bandwidth of 8 MHz, while simultaneously performing up to 2,500 position fixes per second locally, if somewhat higher power levels were used.

Operation of the 16 MHz bandwidth experimental system confirmed that this time-for-a-position-fix will result in a projected throughput rate of more than 1,500 randomly addressed, and 3,000 group addressed vehicular position fixes per second near a local cluster in a commercial system based on an 8 MHz authorized bandwidth, when operating with a Cramér-Rao bound of 4.75 nanoseconds and a two dB higher worst-case IF s/n ratio of - 8 dB. The predicted effective raw data rate accompanying the



position fixing in such a commercial system in the 8 MHz bandwidth would be 364,000 bps.

C. Measured Time-Synchronization Overheads,  
"Time-Slicing" and Competition

The synchronization airtime overhead for Pinpoint's experimental system is less than 0.17%. The equivalent timebase synchronization overhead for a fully-functional commercial system is projected to be less than one percent. A spread sheet showing the effect of such low overheads on the "waste" of airtime by sharing operations is shown in Figure 1.

While this presentation adheres to the principles illustrated by Richard Schmalensee in Appendix 4 of Teletrac's comments, the numbers derived from Pinpoint's results undermine his conclusions. Even with a relatively large number of market participants, the synchronization overhead "costs" of sharing are moderate. The alternative is a duopoly offering restricted consumer choice and virtually no incentives for innovation. Such an approach would be inconsistent with the objectives identified by the FCC in the NPRM.

Teletrac's assertion that competition will lead to the "destruction" of the band's usefulness is incorrect. With the proposed time-sharing of the band, and with entry limited to genuine operators with real, demonstrable technologies and systems, and with strict assignment/transfer rules and construction deadlines, entry into the band will be self

limiting. There will be little to gain by speculators. Only those with sufficiently high-performance technologies to viably enter the market will be able to survive, and those with marginal (or no) performance will be eliminated by the natural action of the market.

Pinpoint's experiment has also shown the feasibility of time-division sharing between wide-area systems positing a simple 50%-on, 50%-off scheme. Central to the test was synchronizing the ARRAY™ system for time-slice operation with reference to a standard time signal. This has been achieved without incurring any additional time-synchronization airtime overhead. Signals from the time reference interrupt the control processor in the master base station at regular intervals. Software then initializes the ARRAY™ network's master clock to restart near the interrupt. Because the activity is local and software-controlled, no additional airtime is consumed over that amount otherwise required for the remote base station synchronization/calibration functions.<sup>9</sup> Therefore, Pinpoint's system demonstrates that not only is simple time sharing of the band possible, it is possible without incurring the "tremendous waste of spectrum" predicted by other commenters.

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<sup>9</sup> The philosophical design underpinnings of the airtime scheduling approach used by the system is such that extending the time-sharing to more flexible schemes that make dynamic sharing of the band possible can be accomplished with manageable levels of cooperation between sharing participants.

D. Coexistence of Part 15 and Wide-Area Predicted Effects of Pinpoint's High-Powered, LMS is Practical.

Interference modelling and some field measurements have led Pinpoint to expect that while some mutual interference is theoretically possible between wide-area LMS systems and Part 15 devices. In general, however, coexistence in the band is practical. The power for wide-area systems should not be constrained as suggested in the NPRM, and the more realistic power limits proposed by Pinpoint should be adopted. Generally, the performance of Part 15 devices will be less affected than the wide-area systems.<sup>10</sup> This is primarily the case because of the short-range nature of the Part 15 devices (up to a few thousand feet), whereas, by definition, the wide-area systems are working over significantly larger distances (1 to 10 miles).

As an initial matter, it should be noted that the level of interference caused by vehicular transmissions will be insignificant. A given vehicle will transmit very infrequently (once per second maximum, with less than 1% duty cycle, and an average less than once per few minutes). Base stations, however, could transmit with a randomly varying duty cycle, up to a maximum of about 30% for short periods consisting of randomly spaced short bursts (lasting from 300 microseconds to 15

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<sup>10</sup> The maximum power for a broadband forward link proposed by Pinpoint (i.e. 625 watts/MHz spread over at least 2 MHz up to 5 kw) is consistent with (and somewhat less than) that which can be authorized under Section 90.239 today (e.g. 1 kw into a 10 dB gain antenna).

milliseconds). These transmissions are not continuous nor predictable, except for synchronization transmissions which occupy less than 1% of the base station's actual operation, as discussed above.

15 device was 8 dB (giving about 12 SINAD using narrow-band FM), then the allowable path loss for the Part 15 device could be  $+20+30-55-8 = 97$  dB. Assuming that the path loss is due to free-space propagation yields a communication range of about a mile. Allowing for an additional 15 dB signal attenuation from building penetration, a 1000 foot communication range could be expected in the presence of Pinpoint's system.

The situation for wideband Part 15 devices is, however, not as easy to consider, due to the large number of variation in design and trade-off choices available to spread spectrum designers. Narrowband, frequency-hopping devices should enjoy performance similar to that outlined above. Broad-band, direct-sequence devices, or broad-band frequency-hopping devices are more problematic to analyze due to the wide latitude in the systems termed "broad-band". In general, broad-band devices will intercept more of the jamming energy from a wide-band AVM system, and will generally only have moderate processing gains. For an illustration consider the following example:

A broad-band, direct sequence device uses a 4 MHz IF bandwidth for a wide-area data reticulation scheme. The device uses a 1K chip sequence, yielding about 30 dB processing gain, and the detector margin needed for adequate BER is 10 dB. The transmitter uses a full 1 watt power output and a 6 dBi gain.

permissible path loss under these conditions is  $+36+30-(-60)-10 = 116$  dB. Assuming path loss that is part way between free space and UHF land-mobile propagation models, these assumptions would yield a communication range of between 2,000 and 4,000 feet in the presence of an ARRAY™ signal.

The very dispersed nature of the radiolocation network base stations would indicate that the level of interference predicted above would tend to be worst-case, since the areas most affected would only be a small proportion of the whole coverage area.<sup>11</sup> Furthermore, in the typically five-to-eight mile spacing between these interference areas, the overall interference levels will be significantly smaller.

Although the above examples do not exhaust the possible interference scenarios, they do support an important conclusion. Specifically, while some mutual interference between wide-area AVM systems and some Part 15 devices will occur, the magnitude of the interference on a system level should be manageable for both users.

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<sup>11</sup> The ratios of the total Part 15 coverage area to the areas in which interference is caused by LMS base stations would typically be between about 5 and 10. Thus, the interference free area would be 5 to 10 times as large as that within which interference was perceived.

E.    Power Level Management as a Means of  
      Ameliorating the Effects of Local-Area  
      System Interference

Pinpoint has consistently maintained that wide-area, broadband AVM systems can co-exist with relatively low-powered local area systems (and Part 15 devices), whether broad- or narrowband. Central to any discussion of this issue is the essential difference between the communication ranges normally employed by the systems involved. Local-area systems, such as modulated back-scatter tag readers, operate over relatively short ranges, a few tens to a few hundred feet. (Part 15 devices operate over a few hundred to a few thousand feet.) By placing the wide-area systems base stations appropriately in relation, generally close, to low-power tag readers, and by appropriate choice of operating power levels, it is possible to reduce the areas in which unworkable interference to the forward link occurs to very manageable levels. As an example, see Figures 4 through 7. They illustrate the size of the signal "blackout" zones that a vehicular mobile of a wide-area system may experience near such a tag reader, for various separations between the base station and the reader station. As the base station moves closer to the local-area installation, the size of the black-out area shrinks rapidly.

Figures 8 - 11, respectively, illustrate the limits on communication range that the base station (mobile-to-base channel) experiences due to "jamming" of the mobile signal by the

tag reader under the same conditions of separation as depicted in Figures 4 - 7.

Looking at all the figures together, we can see that the tradeoffs are: moving the base closer to the reader reduces the area of the "blackout" zone, but at the cost of reducing the mobile-to-base range for that base station. However, the mobile-to-base coverage of the network as a system can be managed by judicious placement of other network base stations sufficiently distant from the base station controlling the blackout zone around the interfering reader system. In this way, the areas over which the co-channel interference is "overwhelming" can be minimized dramatically, and certainly brought within bounds that can be considered "tolerable" to the wide-area system operation.<sup>12</sup>

Due to the close operational distances of the local area systems, and consequent high signal levels, the probability of interference to the local area system by the wide area base stations is very small to negligible. The signal levels at the tag reader due to a half-mile distant wide-area base station would only get up to between -40 and -60 dBm, yielding a large margin in the reader's performance. (The local-area reader typically uses a +30 dBm radiated level to produce a -10 dBm tag reflection measured at the reader.)

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<sup>12</sup> Additional receive-only sites could also ameliorate this situation.

The only circumstance in which the tag reader's margin will be overwhelmed is in the low-probability case of a vehicular wide-area mobile transmitting while in close proximity to the reader station. The probability is low because the mobile would probably be in the blackout zone and not be successfully "polled" by a base station.) Here the very low duty cycle and short duration of the mobile's signal will allow the tag reader to have at least a second opportunity at reading the tag.

**F. Balance of Wide Area AVM Out- and In-bound Links on System Performance**

The RF communication platform on which the ARRAY™ network is built uses a single, broadband, half-duplex link. As noted earlier, this link simultaneously carries both the messaging/protocol data and the time-ranging pulses within the same signal. The result is that no additional radio equipment, airtime or spectrum is required for the two principal functions of the system. System engineering analysis suggested to Pinpoint when designing ARRAY™ that operating the network in half-duplex mode was an important option. Making the link a single broadband half duplex channel allows a common set of the circuitry to perform much of the receive and transmit functions. This design feature produces a tremendous reduction in mobile transceiver complexity and in components. The net effect will be significant cost savings in the radios.

This should help explain why the ARRAY™ system's outbound (forward) link has such a wide bandwidth, a feature some may have found curious. The approach taken in the design of ARRAY™ was to find a single, economic solution that would provide all the radiolocation and bi-directional data communication functions compatible with high power in a single piece of equipment, and in a single wide-area network-function.

An examination of the typical message traffic patterns involved in the management of vehicles (summarized to some extent in Table 2) shows that the inbound (to the network) and outbound (to the mobiles) message volumes are significantly different, with the volume of outbound data being between two and ten times larger. A further examination of the requirements of a high-capacity radiolocating and data network operational protocols, shows that for radiolocation alone, the outbound link can consume a significant portion of the available airtime, unless the data rate of the outbound link is high.

One possible way to reduce a part of the outbound polling traffic is through an outbound link with very wide area coverage, as for example, in the "paging-style" forward link. Here a part of the polling overhead (i.e. the search for the cluster containing the unit being polled) could be smaller because a single outbound poll would reach the whole coverage area. However, the data capacity of such a (narrowband) paging link is small. and additional (narrowband) spectrum and communication

channel equipment, are required. While the narrow bandwidth of the forward link would probably not limit seriously the performance of a radiolocation-only service, it would not offer an optimum or balanced communication solution for vehicle management.

Pinpoint's system approach verified that to minimize airtime a more balanced system, where about the same amount of airtime was being used for both the outbound and inbound links was needed. This required that the bandwidth of the outbound link needed to be similar to the bandwidth of the inbound (mainly radiolocation ranging) link. Hence, the Pinpoint solution: use the same technology for both links, and simplify the complexity (and lower the cost) of the mobile transceiver significantly.

#### G. Response to the Pickholtz Study

Professor Pickholtz's Engineering Analysis touches upon a number of facets of the design and performance of pulse-ranging radiolocations systems. There is much in his discussions concerning the nature and cost of time-sharing as a method for using the band for wide-area AVM/LMS operation with which we do not concur. Most importantly, he does not consider the single most important tradeoff that affects the performance of the Teletrac system, namely the consequences of designing a system to operate at too low a mobile power level to achieve a sufficiently high signal-to-noise ratio at the maximum design range to

overcome the existing and future (e.g., AVM and Part 15 growth) interference in the band in which the system will operate.

It is clear from Teletrac's own submissions that its system was not crafted for the interference conditions present in the band and long made known in public record. (The original 1974 AVM Report and Order and the later 1989 Part 15 Report and Order spell out the kind of interference to be expected.) The fact that Teletrac's system may operate near a Cramér-Rao bound based on a hypothetical s/n ratio does not mean that its system performance in the 902-928 MHz band could not be dramatically improved. It only signifies that the designers did a good job of implementing their receiver and detector system under a certain set of presumed operating conditions. Choices of bandwidth, allowable path loss, and transmitter EIRP do effect the final s/n ratio used in determining the Cramér-Rao bound for those choices. Unfortunately, those assumptions do not necessarily coincide with the real-world operating environment at 902-928 MHz, which presents a wide range of possible interference. A wider examination of the actual operating conditions, including the fact that the interference levels the 902-928 MHz band are likely to reach the -80 dBm level due to growth in the numbers of local-area AVM systems, unlicensed Part 15 devices, and others, shows that the available communications ranges of a system operating at the Cramér-Rao bound based on unrealistic signal-to-noise expectations would be severely restricted.

Teletrac's own records confirm this. In Appendix 2 of Teletrac's comments, "Theoretical & Field Performance of RadioLocation Systems," Teletrac discusses field data measured on an operating Teletrac system in Dallas. The data at Page 13 of Teletrac's Appendix 2, on Figure 9, shows that a single 1 watt interferer near the center of its network reduces the number of base stations receiving mobile signals adequate for an acceptable position fix to 5. This is a similar power level to that which could be experienced from an innovative wide-area, Part 15, data reticulation network, such as those developed by companies like Metricom and others. Such networks intend to be widely deployed, utilizing hundreds of distributed, repeating transceivers. While Teletrac's own documents shows that it is likely that deployment of such a Part 15 system in Dallas would completely incapacitate the Teletrac system, Teletrac disingenuously suggests in their comments that they are "Part 15 friendly."<sup>13</sup>

The bottom line of this exploration is to show that one manageable way out of the co-channel sharing dilemma is through effective power management by the different users of the band, namely short range systems would use low power, and wide-area systems would use significantly larger power. Examples illustrating the workability of such power management have been

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<sup>13</sup> Note, however, that these data from the Teletrac field study also suggest that an increase in power of the mobile unit (which was operating at about -.5 dBw) would yield a significant improvement in the number of receive sites that detect the pulse.

given elsewhere in this Technical Appendix. In addition, Figure 9 of Teletrac's Appendix 2 demonstrates a marked increase in the number of receive sites that could be used for position fixing if its mobile units utilize only 10 dB more power. (They currently operate at an EIRP of about 1.25 watts depending on antenna choice.) Perhaps in retrospect, PacTel's choice to deploy a system using too little power to meet the link margin criteria for existing conditions was foolhardy -- even if it may have permitted designers to meet some arbitrarily low cost criterion.

As noted above, Pinpoint has advocated from the beginning of this proceeding that a practical alternative exists to exclusivity for existing licensees, which would effectively reserve the 902-928 band nationwide for only two operators of

wide-area radiolocation systems (Teletrac and METS).<sup>14</sup> That approach is time-sharing.

In support of eliminating competing market entrants, Teletrac has hired consultants to critique the feasibility of this approach to efficient band sharing. Professor Pickholtz is far too eager to dismiss simple time slicing -- which is understandable when we consider who his client is. Let us focus on simple, fixed period, time slicing.<sup>15</sup>

We thereby sidestep all of the rhetoric about the difficulty of deciding what rules to use. We leave it to the successful

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<sup>14</sup> The currently issued licenses to these entities cover 80% of the United States population. The remaining markets are currently not viable to warrant the deployment of wideband, wide area systems. It seems that at some point in the past Teletrac may have thought that the band was going to be quieter than it has turned out to be. If one reads Teletrac's original license filings, one notes that the output power level of its mobiles was specified at a maximum of 158 watts ERP or about 21 dB above its actually implemented level of about 1.25 watts ERP. If Teletrac were now operating at that originally proposed signal level it would not be having nearly the problems of which it is now complaining. It seems that at some point between filing for its license and deploying its system, a decision was made to "go for a different target," and it turned out to be the wrong one. Now Teletrac is expecting the rest of the LMS industry to pay for its "mistake".

<sup>15</sup> Professor Pickholtz quickly dismisses several red herrings: Carrier Sense Multiple Access (CSMA); Token Passing; Code Division Multiple Access (CDMA). We agree with the Professor -- we don't believe these are the right approach. Therefore, we concentrate in these reply comments on the two simple means of orthogonally dividing a piece of bandwidth: fixed frequency division and fixed time division. We believe that there are time division scheduling approaches that are superior to fixed time slicing but we will not discuss them here -- *simple fixed time slicing is far superior to frequency division.*

licensees to determine if they want something better than fixed time slicing -- we merely insure that they have the opportunity to avail themselves of the enhanced performance those rules could deliver. We are even willing to forego the dynamic capacity sharing that more advanced forms of time division could deliver because there is no possibility of getting dynamic capacity sharing in a frequency division environment. **Fixed time slicing beats out frequency division -- possible gains from dynamic slicing are just gravy.**

This only leaves Professor Pickholtz's fears about the difficulty and overhead in implementing a time slicing function. He need not have worried -- Pinpoint has already implemented a workable solution. As detailed earlier, Pinpoint has built, and is operating experimentally the most advanced "non-military" radiolocation and mobile packet data system in existence. Pinpoint has conducted experiments to explore the complexity and cost of operating the systems stand-alone as well as time-sliced with another system on a 50-50 sharing basis with half-second-on, half-second-off timing. Pinpoint has also explored the complexity and cost of synchronizing the system with a reference signal, (e.g., GPS) such as would be used to coordinate the operation of multiple co-channel wide-area systems.

As explained above, synchronization overhead air-time "costs" are much less than one percent of capacity whether one is operating in a time-shared environment or standing along. When

overhead values like this are used in both Professor Pickholtz's and Professor Schmalensee's arguments against time sharing, it can be seen that while there is some price being paid for complexity, direct capital cost, "difficulty", and system capacity reduction, it is small and manageable for any "reasonable" number of market entrants.

Professor Pickholtz suggests that certain features of a system's performance may be slowed down under timesharing. However, the magnitude of any slowdown depends upon the sharing algorithm. The slow-down effects are worst in the case of the very simplest mechanism for sharing the band: round-robin time division with fairly large time slices (several seconds or more). Of course, the time slices can be much smaller, as Pinpoint's system results prove, and need not be strictly round-robin.<sup>16</sup> Other mechanisms, like forward scheduling, have even more capability of addressing most of Professor Pickholtz's objections. This involves scheduling time slots for the sharing systems dynamically in the future, typically several seconds in advance. Scheduling can potentially be much further in advance for regular, periodic events, such as security monitoring.

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<sup>16</sup> Token-passing may be an effective mechanism for local area networks with very reliable and fast (small latency) communication mediums (typically a copper or fiber bus). But it is not a suitable mechanism for widely dispersed control centers of wide-area AVM operations where the token passing is less secure and subject to significant propagation delay latencies. Consequently it is unlikely that it will ever be implemented as a viable sharing control mechanism.

Professor Pickholtz also looks at the perceived need for "asynchronous" operations. "Asynchronous" operations relates only to the perceived performance of the system by the user, i.e., the latency between a request for action and the response to it. With an appropriate, synchronized protocol structure, latency delays for "priority" activities can be easily reduced to manageable proportions consistent with any demand for asynchronous operation.

In his analysis, Professor Pickholtz states that adding a second cellular operator to the cellular band only increased the network infrastructure costs by 15%, but that adding a second LMS operator would purportedly add more than 100% to the cost. Pinpoint wonders where the second cellular operator got its system so cheaply. The second entrant apparently had to build out its system fully (i.e., at roughly a full 100% of the cost of the first cellular system). Furthermore, the incremental increase in system operating cost depends on system loading, implying that it is at its maximum when the system is installed and there is only one marginal consumer of its services. As the volume of services increases, the marginal cost goes down. Therefore cost will increase nearly equally whether using time-sharing or frequency sharing, but a competitive marketplace created by time-sharing will justify such expenditures.

PacTel makes light of frequency sharing at less than 8 MHz, but glosses over the fact that throughput varies as the square of

occupied bandwidth (for a white gaussian noise limited communication channel) or, as Pinpoint has shown is more likely to be the case in this band, as the cube of the occupied bandwidth (for the narrowband interference limited environment). Professor Pickholtz's position threatens to hide a very significant factor for efficient use of the band. The implication of the relationship is (generally) that to maximize the service value of the band, an operator should have access to the greatest amount of available bandwidth so that the service it is offering can be completed in the shortest time.<sup>17</sup> There are other factors affecting the position-fixing rate, like maximum-range signal flight times and minimum protocols overhead times that set practical limits on the maximum amount of spectrum that can usefully be utilized, but these do not overcome the benefits of maximizing bandwidth.

Modeling has shown that many practical systems can effectively make use of up to the full 26 MHz without incurring spectrum wasting. However, to obtain quality access to the band, each user needs to have exclusive (amongst wide-band, wide-area, LMS service providers) access to the band *while they use it*. Multiple entry can be accommodated consistent with this principle in one-way: time-sharing. At the transmit power levels that wide-area LMS service providers must necessarily operate at, in

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<sup>17</sup> See Figure 12 for an illustration of the bounds around practical position fixing system designs.

order to operationally tolerate the low-powered, local-area service providers, the record suggests that wide-area operators cannot practically share spectrum by any other known co-channel operating technique, like CDMA or frequency hopping, (other than frequency division. But this is not co-channel sharing and would impose severe capacity limits as the band is split to support two or more competitors.

Both the Teletrac and proposed METS radiolocation technologies used PSK modulation schemes with approximately 2 Mch/s chipping rates. They claim that they require at least 8 MHz of spectrum within which to contain the resulting signals "economically". They claim that it may even be impossible or infeasible to implement filters to adequately contain the signal to the bandwidth of the "main lobe", of about 4 MHz nominal bandwidth. The cost of their assertion is that between them 8 MHz of spectrum is being used for "guard band" for poor engineering! Contrary to the claims of both METS & Teletrac, it is entirely possible to build filters to effectively contain the transmitted bandwidth to about twice the chipping rate. In Pinpoint's experimental system, now in operation in Washington, D.C., such filters are used to contain more than 99% of the energy of an 11 Mch/s MSK signal, with a 10 MHz 3 dB bandwidth, to within the allocated 16 MHz experimental bandwidth. (The same filters also help to reduce the interference from other 900 MHz signals that are close to the 928 MHz band edge.) The

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